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A Variable Approach-Angle Moldboard Plow

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ABSTRACT

A moldboard plow was modified such that the approach-angle of the bottoms could be varied and held at a given angle by a hydraulic cylinder. Field tests of this plow verified that good plowing performance could be obtained at high travel speeds when the bottoms were operated at an approach-angle less than the design approach-angle.

INTRODUCTION

One method of reducing the production cost of farm crops is to increase the capacity of field machines. One method of increasing this field capacity is to increase the forward speed. This concept presupposes that sufficient drawbar power is available, but has the advantage of not requiring a high tractive effort from the ground drive components of the tractor.

Traditionally, one of the fundamental problems associated with highspeed tillage is that the draft requirement of the implement increases with the forward velocity of the implement (McKibben and Reed, 1952). This has been particularly true with moldboard plows; the draft at 20 km/h being in the order of 150 percent of the draft at 5 km/h (Hunt, 1973, p. 71). If the lateral component of the soil velocity can be held constant, this increase in draft with forward speed can be curtailed. By reducing the wing angle of the body (Söhne, 1960, p. 21), a plow can be designed to operate at any given speed up to approximately 16 km/h. If the given speed is exceeded, the draft requirement will rise steeply and if the speed cannot be attained, the plow will not do a satisfactory job of inverting the soil.

Studies at Iowa State University (Eidet, 1974) indicated that, by varying the approach angle of the plow, the draft increase as a function of speed could be markedly reduced.

CONSTRUCTION OF THE VARIABLE APPROACH-ANGLE PLOW

The Allis-Chalmers Corporation donated a 3-furrow version of its 2000 series plows to be converted to a variable approach-angle plow. The original design and construction of the plow modification was a Senior Design Class Project at Iowa State University for students enrolled in the Agricultural Engineering 435 and 436 design courses in the winter and spring of 1975.

The plow was modified by removing the individual bodies, installing the necessary framework, and repositioning the bodies onto beams that would rotate through an angle of 15 deg, from the original design approach-angle of 35 deg to an approach-angle of 20 deg. One design parameter was that the width of plowing would not change with the approach-angle; (therefore, the hinge points for the rotating beams were positioned directly above the tip of the share.) This concept is illustrated in Fig. 1. The landsides were removed and the frogs were repositioned to prevent interference with the furrow wall when the plow was rotated to its minimum angle.

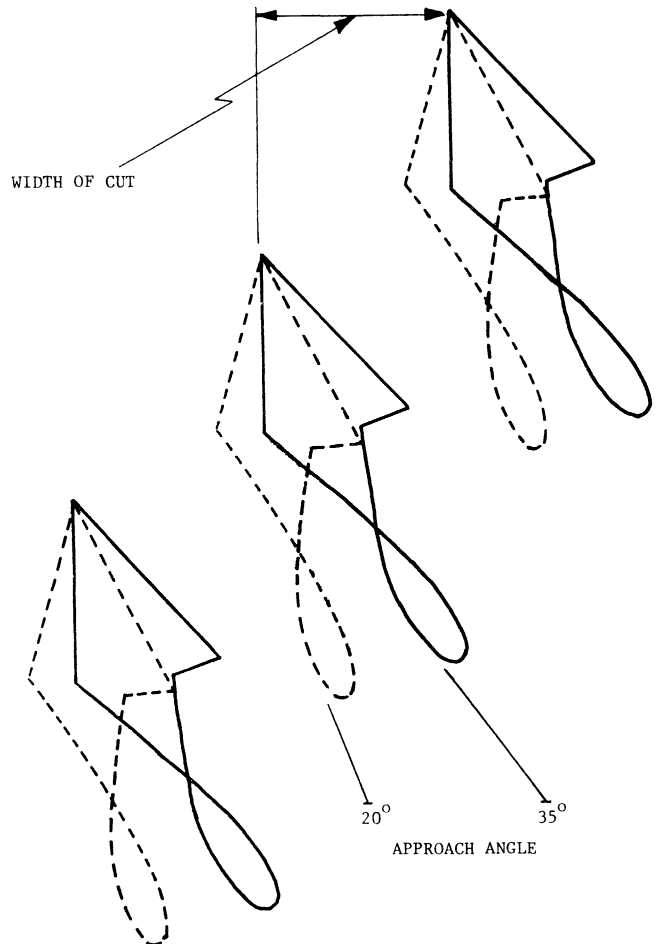

FIG. 1 Width of cut at all approach angles does not change.

The basic construction of the modified plow is shown in Figs. 2 and 3. A detailed description is available in the "Design Report of a High-Speed, Variable-Angle Plow", (Goeken, Rieck, Dittmer, Kajewski, and Becicks, 1975) available from the Iowa State University Agricultural Engineering Department. Fig. 4 shows the approach-angle set at 35 deg, and Fig. 5 shows it set at 20 deg.

As a result of preliminary testing, the plow was subjected to further modifications: the rotating beams were strengthened, the share points were extended to the left side to increase penetration at small approach-angles, the plow tail wheel was repositioned some 180 mm nearer

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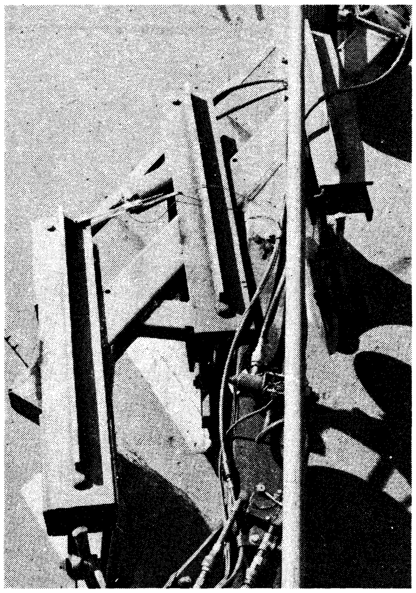

FIG. 2 Basic construction, overhead view.

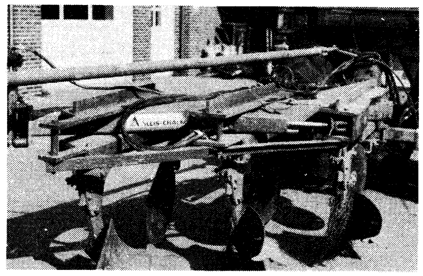

FIG. 3 Basic construction, rear view.

FIG. 4 Approach angle set at 35 deg.

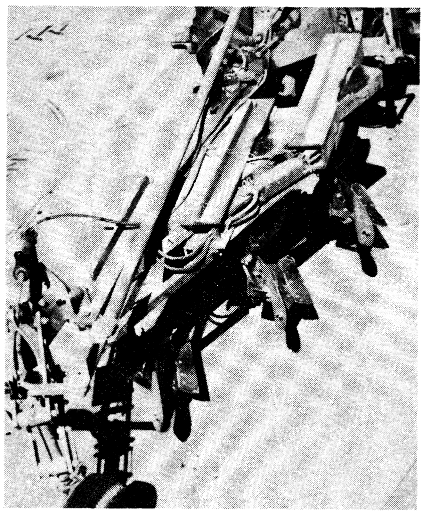

FIG. 5 Approach angle set at 20 deg.

FIG. 6 Modified share point.

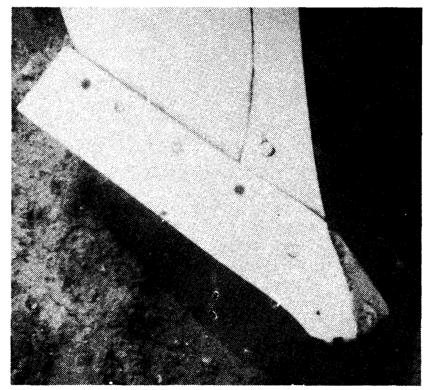

FIG. 7 Modified share point.

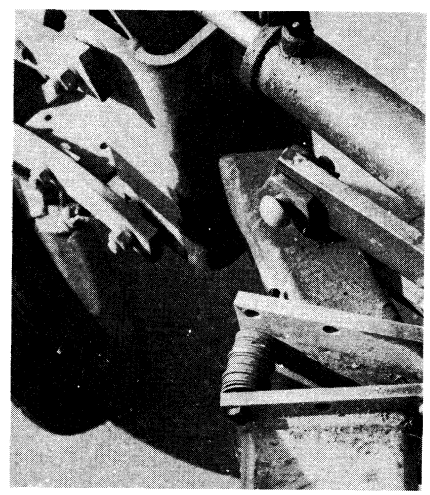

FIG. 8 Modified mounting frame to change the plow wheel position.

to the furrow wall, and the manufacturer's stabilizing bars were fitted onto the lower links of the tractor. The modification to the share points is illustrated in Figs. 6 and 7, and the method used to reposition the plow wheel is shown in Fig. 8.

The share points had to be modified because the plow would not penetrate the soil at any approach-angle other than the design approach-angle of 35 deg. This was thought to be a manifestation of the blunt side, rather than the sharp tip, of the share attempting to lift the furrow slice up onto the moldboard. The stabilized lower links and the repositioned plow wheel were methods employed to make the plow run in line with the tractor.

At this time, problems were encountered with soil not being completely inverted and falling back into the furrow bottom. This is illustrated in Fig. 9. (The grid board, marked off in 100 mm squares, shows the relative size of the clods of soil). This was thought to be related to the use of an over acute approach-angle at any given speed, which might be overcome with an automatically adjusted approach-angle/speed relationship.

AUTOMATIC CONTROL OF THE APPROACH-ANGLE

Up to this time the approach-angle of the plow had been altered by the operator, using hydraulic power from the tractor. This method did not provide precise control and the approach-angle was not accurately related to the forward speed. A combined electro-hydraulic system was developed to provide automatic control. Fig. 10 il-

FIG. 9 Clods of soil lying in the furrow bottom.

lustrates the logic involved in this mechanism and Figs. 11 and 12 show the circuit diagrams for the electronic and hydraulic systems respectively.

A DC generator, driven by the plough wheel produces the negative voltage noted in Fig. 10. This voltage is directly proportional to speed. A potentiometer, position controlled by the approach-angle, puts out a positive voltage proportional to that angle. These two voltages are algebraically added to leave a differential voltage (ΔV). This ΔV is then amplified to control one of the solenoids in the double-acting hydraulic valve. The system used dual operational amplifiers (op-amp), each of which has the same signal applied to it. However, the output of each op-amp is not the same. When ΔV is positive op-amp number 1 will go positive, and op-amp number 2 goes negative; ie, op-amp number 1 has the same sense on output as on input, and op-amp number 2 has the opposite sense on output as on input. The penultimate

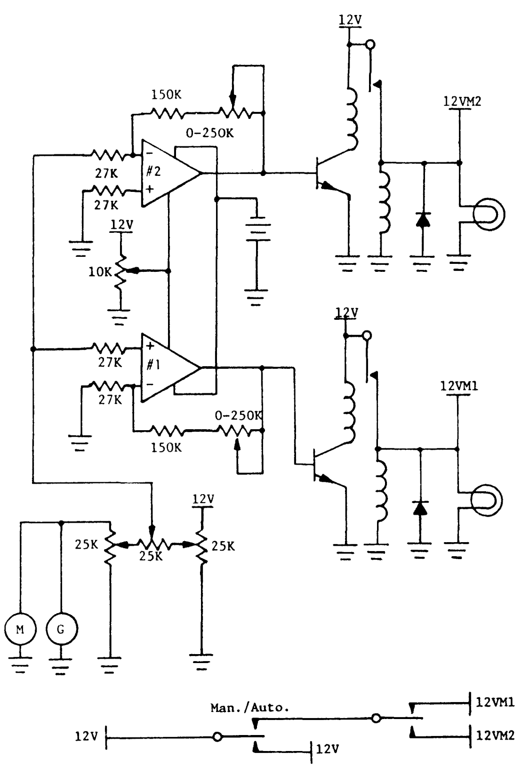

FIG. 11 Electronic circuit diagram showing automatic control of approach angle.

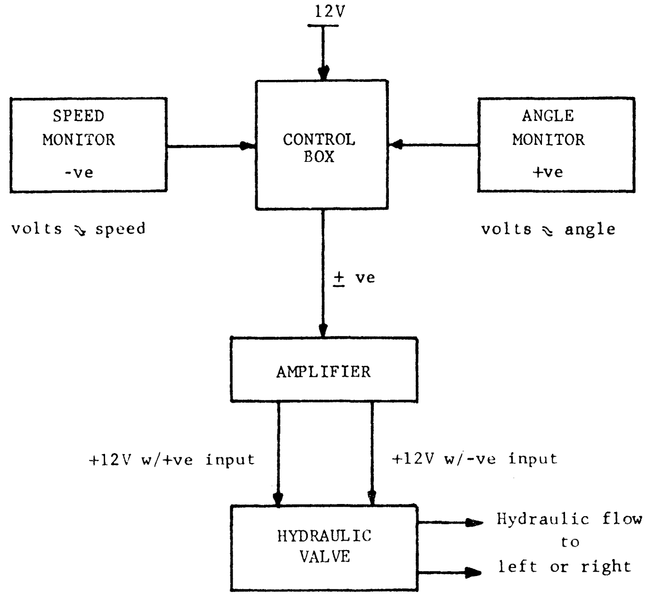

FIG. 10 Control system logic diagram.

stage on each output is an npn transistor (positive base with respect to emitter to turn on). Thus, with a positive ΔV op-amp number 1 goes positive thereby turning on transistor number 1 and, via a relay solenoid number 1. If ΔV goes negative, the output of op-amp number 2 goes positive, turning on transistor number 2. Hence, there is a separation and control of the two solenoids which is dependent only on whether the input signal to the amplifiers is positive or negative.

For example, suppose the forward speed generator puts out a negative voltage greater than the positive voltage from the angle potentiometer, indicating an increase in speed. The resultant negative ΔV activates op-amp number 2 and, thus solenoid number 2. Number 1 tronsistor and number 1 solenoid are, in effect, driven farther "off". Solenoid number 2 directs the hydraulic power circuit to decrease the approach angle. This angle reduction in turn rotates the potentiometer and increases the positive voltage, which opposes the negative voltage from the generator. When the two voltages are equal and opposite there is no signal to the op-amps, and number 2 op-amp shuts off. In the same way, as the speed slows down, the same series of events activates the solenoid controlled by op-amp number 1.

The activation of one of the two solenoids in the electro-hydraulic valve directs the flow of oil to the hydraulic cylinder that alters the angle of the moldboard to reduce or increase the approach-angle. A volt-meter, wired in parallel with the speed generator and calibrated

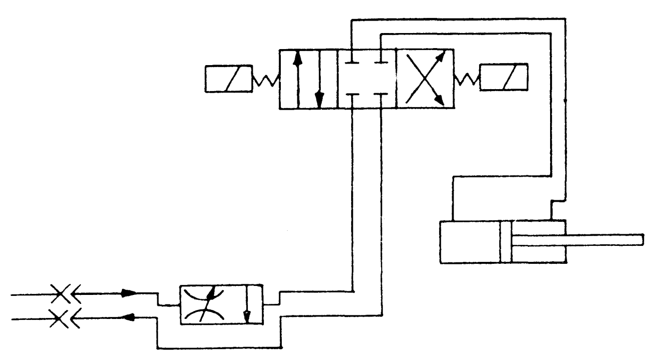

FIG. 12 Hydraulic system.

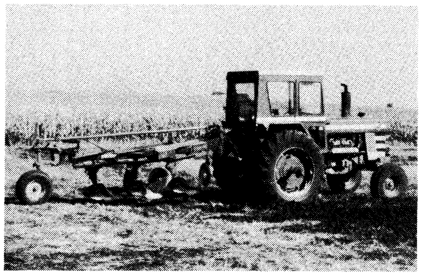

FIG. 13 Condition of surface prior to plowing.

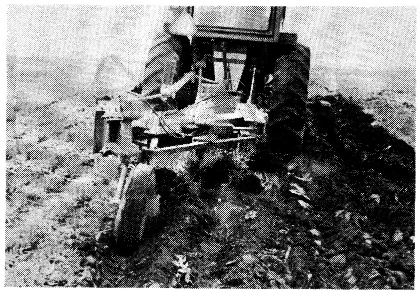

FIG. 14 Quantity of surface trash before plowing.

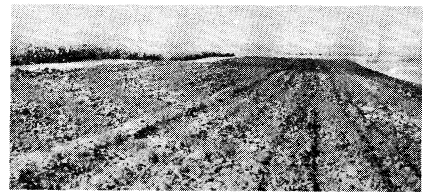

FIG. 15 Overall view of plowing at various speeds and angles.

FIG. 16 11 km/h, 28 deg approach angle.

FIG. 17 13 km/h, 20 deg approach angle.

FIG. 18 14 km/h, 20 deg approach angle.

in km/h gives the operator a visual indication of forward speed. The 12 V power supply to the electronic circuit is directed through a single pole double throw switch to provide for manual or, as previously described, automatic control of the system.

TESTING OF THE PLOW

The plow was tested at Iowa State University's Agricultural Engineering Research Farm, the objectives were:

1 To find out if the plow would perform as a tillage tool under field conditions.

2 To evaluate the quality of plowing at various speeds.

The tractor used in the tests was a Massey-Ferguson 1150. It was subjected to a PTO maximum power test and found to be capable of developing 96.6 kW (129.5 hp).

Figs. 13 and 14 show the condition of the soil surface before plowing. Figs. 15 to 19 illustrate subjectively the quality of plowing produced at various speeds. These illustrations refer to comparatively high speeds because it is at the higher speeds that a poorer quality of work may be expected. Automatic angle adjustment was used at all times and the depth was held constant at 200 mm. The overall quality was deemed quite good in terms of trash coverage and eveness of finish. In our opinion it would be acceptable to most Iowa farmers. The size of clods on the plowed surface varied little, despite changes in forward speed. It was not unitl the speed was reduced below 5 km/h and the approach-angle increased to 35 deg maximum that the individual furrows became clearly distinct. In this particular test, this occurred only at the start and finish of each run. It was concluded that the evenness finish was a result of the fine adjustment of the speed/angle relationship made possible by the automatic control mechanism.

Throughout the testing no scouring, electrical, or mechanical problems were encountered. As illustrated in Fig. 19 the soil showed little tendency to fall back into the furrow bottom and the rear wheel of the plow did not bounce or ride out. This was aided by having a relatively "clean" surface for the wheel to travel on, but nevertheless would also signify that the side draft on this wheel did not increase with speed.

From observations made by all the operators, it was

FIG. 19 14 km/h, 20 deg approach angle. No soil fallen back into the furrow bottom.

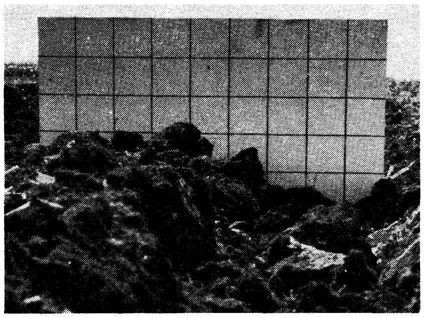

FIG. 20 Grid board used to measure soil profile.

apparent that noise and vibration in the tractor cab were at an unacceptably high level when travelling at high speed. This problem was undoubtedly compounded by the general wear and tear on the cab mountings, but certainly indicates the desirability of insulating the driver from the noise and vibrations. At the higher speeds the operator did not have time to visually monitor the plowing and, if the manual control was being used, only had time to make the coarsest adjustments to the approach-angle. The problems of concentration and comfort became less significant as the operators' increased their skills with further practice. The problem was also noticeably less when the surface of the ground was relatively smooth.

The plow was equipped with the manufacturers' springloaded trip mechanism on each body. This mechanism frequently tripped, particularly when high speed operation was attempted at the greater approach-angles, indicating that the plow was being subjected to draft levels greater than normal. To prevent excessive tripping the spring pressure on the trip mechanism was increased.

With the approach-angle held constant at 35 deg the maximum attainable speed of the tractor pulling the plow was 8 km/h. The maximum speed obtainable during the test was 15 km/h. Under the prevailing conditions of soil strength and moisture content during the test the maximum speed, considered by the operators to be practical, was 12 km/h. This was the highest speed obtainable in 4th gear. To exceed this speed 5th gear was required, but there was insufficient torque available to accelerate to rated engine speed.

Wheel slip was not measured in as much as it was not visually detectable at any time during the test. The surface of the soils was still damp from recent rainfall, but conditions would be considered by farmers to be ideal for plowing.

To further evaluate the quality of plowing a series of soil profiles was recorded on film and prints were made of the resulting pictures. Fig. 20 shows the grid board used to record the soil profile the board was marked off in 100 mm squares and was inserted into the furrow section, resting on the furrow bottom and with the left-hand

TABLE 2. ANALYSIS OF VARIANCE

Source	d.f.	SS	MS	F
Between speeds	6	58.11	9.69	6.42*
Within speeds	21	31.63	1.51	
Total	27	89.74		

*Significant at the 0.01 level.

TABLE 1. DISTANCE OF THE CENTROID FROM THE FURROW WALL

	Speed, km/h						
	3.2	4.8	6.4	8.0	9.6	11.3	12.8
	23.8	24.0	25.4	26.4	21.6	23.6	21.5
	23.5	25.1	23.0	23.8	23.6	22.0	21.2
	26.0	21.0	23.0	28.0	20.0	23.8	21.4
	24.1	23.1	24.0	25.1	21.1	23.0	21.3
Mean	24.35	23.53	23.85	25.83	21.60	23.10	21.35

L.S.D. $P < 0.05 = 1.81$

edge against the furrow wall. The orientation of the camera to the board was the same for each photograph. The centroid of the soil mass, reflected against the white board, was determined by cutting away that part of the picture devoted to the soil profile and locating the centre of gravity of the soil mass. To obtain this center of gravity, the cutting was suspended from each of three different positions, and the corresponding plumb lines were placed on the surface. The intersection of these three lines located the center of gravity. The distance from the centroid to the furrow wall was used as a score for each picture. Speeds, in 1.6 km/h (1 mph) increments, from 3.2 to 12.9 km/h were thus scored, by the use of four randomized duplications for each speed. These scores are shown in Table 1 and the associated analysis of variance is shown in Table 2.

The null hypothesis was that there was no difference in the scores, but the "F" test indicated that there was a difference. Fig. 21 shows the graph of the score means vs. speed. It was expected that the centroid value would remain the same, but the general decline of the values, once the speed exceeded 8 km/h, indicated that the plow was not throwing the soil as far to the side at the faster speeds as it was at the slower speeds. This phenomenon would suggest that there was no increase in the lateral component of soil velocity and, hence, no increase in the side force on the moldboards. It would also explain why the tail wheel of the plow, which carries the side thrust, did not exhibit any tendency to ride out of the furrow bottom as the speed increased.

SUMMARY

A fundamental problem concerning the use of high-speed moldboard plows is the drastic increase in draft in relation to forward speed. A "high-speed" moldboard can be designed, but will not produce satisfactory results if the "high-speed" is unobtainable. Previous studies on high-speed plowing, conducted at Iowa State University, indicated that draft could be reduced by rotating the plow bodies and thus altering the approach-angle, this had not been demonstrated under field conditions before.

A modification to provide an adjustable approach-

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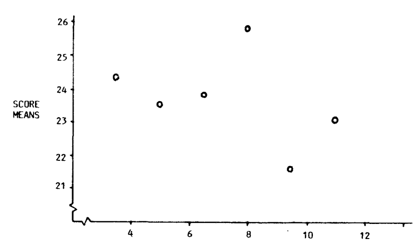

FIG. 21 Score means vs speed.

Variable Approach-Angle Moldboard Plow

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angle on an Allis-Chalmers 3 furrow plow was designed and constructed by senior agricultural engineering students at Iowa State University. We then equipped this modified plow with an electro-hydraulic mechanism to automatically control the approach-angle. The plow was then tested under field conditions.

The results of this testing supported the previous hypothesis that draft increase, as a function of speed, could be noticeably reduced by rotating the plow bodies and, because of this, the speed of the plowing could be increased. Because of the speed/angle relationship the machine would do a satisfactory job of plowing at any speed within a given practical range, or alternatively would work satisfactory at the maximum speed of any given range of tractors. The level of skill required by the operator increased as the speed increased particularly when the approach angle of the plow was altered by the tractor operator. The operator's comfort decreased as the speed increased and would not be conductive to work at high speed.

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